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PARAMETERISATION OF AN AUTOMIZED PROCESSING CHAIN FOR MERIS DATA OF SWISS LAKES, AT THE EXAMPLE OF LAKE CONSTANCE

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ABSTRACT

The physically based Modular Inversion & Processing System (MIP) is used in a processing chain for inland water constituent retrieval from MERIS level 1B full resolution data. Reformatting, data import, water/land masking, atmospheric correction and water constituent retrieval are fully automatized, in order to allow the efficient analysis of large data quantities in a time series of water quality in Swiss Lakes. To account for the temporal variation of atmosphere and water properties, a set of input parameters is optimized specifically for Lake Constance. The algorithm's sensitivity to its input parameters is studied, allowing the derivation of a first guess parameterization. Results of successfully processed data are presented and reasons for processing errors are discussed.

1. INTRODUCTION

Monitoring of water quality in lakes is required as an integral part of water resource management, in order to guarantee the sustainable use of water and to track the effects of anthropogenic influences. Simultaneously, adequate monitoring is required to report the effects achieved by management programs. In situ water quality monitoring of the large glacial and fluviglacial Swiss lakes was established in the 1950s and 1960s. It takes into account a broad range of water quality parameters at decent temporal resolutions, but is limited in the spatial dimension. The MERIS instrument onboard ENVISAT offers increased potential to support established monitoring programs by means of remote sensing, and thus complement them with spatially resolved data. However, MERIS level 2 water constituent products were found not to be accurate for inland waters [1]. Remarkably improved results were achieved by customizing retrieval algorithms to lake specific properties [2] [3].

In this work, an automatized processing chain is used for the retrieval of water constituents from MERIS level 1B full resolution data [4]. 57 datasets covering the years 2003 to 2006 in approximately fortnightly temporal

resolution are considered in this study. Single lake croppings are extracted from each MERIS scene and used as input for the physically based Modular Inversion & Processing System (MIP) [5] [6]. MIP is well automatable, as it performs image based aerosol retrieval and atmospheric correction in advance of the water constituent retrieval. To run MIP in simple, non-iterative batch mode, preliminary input parameters are needed, such as the inherent optical properties of water constituents or channel weighting factors for the retrieval algorithm. We examined the algorithm's sensitivity to these parameters, and began the optimization of a set of parameters for Lake Constance, in order to account for the temporal variety of atmospheric and limnological conditions.

2. INPUT IMAGERY

57 MERIS level 1B full resolution datasets were delivered as 1153 square pixel quarter scenes ("imagettes"), at a nominal ground resolution of 260x290 m. The data are geolocated but not geometrically corrected. An atmospheric correction using the ESA processor is also not applied, but a large set of metadata is provided within the files delivered in the proprietary PDS format [7]. The data covers the years 2003-2006 in approximately biweekly resolution. The images were chosen not only in view of Lake Constance, but for further analysis of other Swiss Lakes. Therefore, Lake Constance is almost entirely cloud covered in 11 and partly visible in 10 datasets, leaving 36 scenes cloudless.

For further processing, the PDS files were converted to HDF format, making use of the batch executable "pds2hdf" contained in ESA's free EnviView application [8]. Specific IDL routines and the longitude and latitude grid values contained in the image metadata are then used to extract single image clippings for each lake (Fig. 1). The output is saved in MIP-readable BIL-files and the respective input file structure for MIP processing modules.

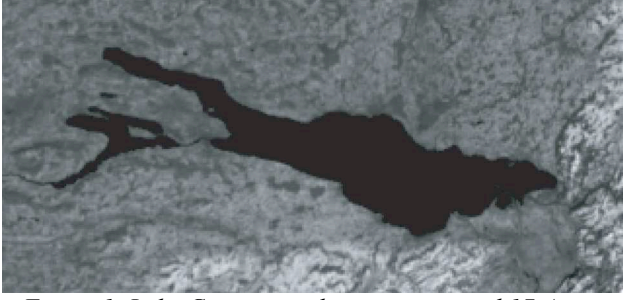


Figure 1. Lake Constance clipping, acquired 17 Apr. 2003, depicted as channel 14 (885 nm) greyscale.

3. Image Processing

3.1. MIP Setup

MIP consists of several modules for the retrieval of water-related parameters from remote sensing data [5] [6]. The two modules used in this work are simple (meaning non-iterative) batch executables that accomplish land/water masking and atmospheric correction, and water constituent retrieval, respectively. The water constituents retrieved are chlorophyll a (chl-a), yellow substance (y) and suspended matter (sm). MIP is used with a main radiative transfer database, built from simulation results of a coupled, plane-parallel atmosphere-water model, by use of the finite element method (FEM) [7]. This main RT database contains a variety of optical properties for atmosphere and water at high spectral resolution and for a large set of geometries. For each image cropping to be processed, a mission specific RT database is extracted, accounting only for sensor parameters and for the image specific observation and illumination geometry (Fig. 2).

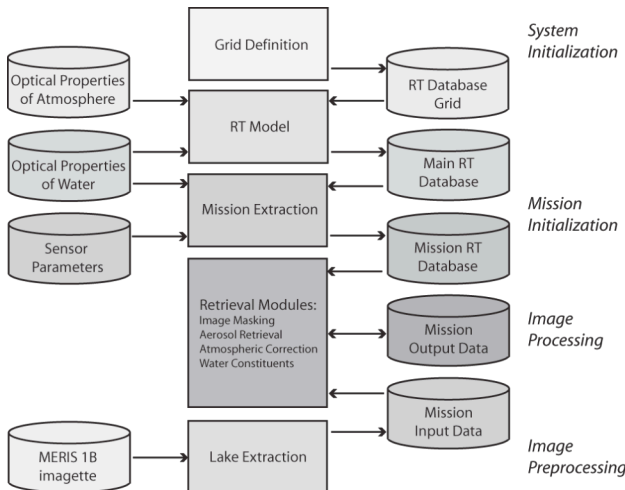


Figure 2. Flow chart of image preprocessing (lower workflow) and MIP processing (upper workflow). Dark shading indicates work progress (modified from [3]).

3.2. Land/water masking

As input for land/water masking, estimates of aerosol type (continental, maritime, rural) and aerosol optical thickness (AOT, at 550 nm) are needed. The thresholds for land/water discrimination are set according to typical values of subsurface reflectance, regarding different channels between 680 and 800 nm, and performing a first-guess atmospheric correction with fixed initial values of AOTs. The output files contain unchanged at-sensor radiances from respective input dataset above water, and zero values above land. We tested the masking procedure with the Lake Constance imageries, using aerosol types continental and maritime and different estimations for AOT. It was found that in some scenes, too many pixels were masked land, while no land was found to be wrongly masked as water. Accordingly, we set the initial aerosol type to maritime and AOT to 0.05 for further processing.

3.3. Atmospheric correction

To correct for atmospheric influence, the parameters to be estimated are again aerosol type and the spectral backscattering coefficient and average concentrations of sm. Furthermore, a NIR reference channel has to be chosen. Subsurface irradiance reflectance is calculated according to assumed water optical properties. The AOT for the estimated aerosol type is then retrieved pixelwise, connecting the calculated reflectance to the measured at-sensor radiance in the reference channel. These AOT values are used to convert the at-sensor radiances in the remaining channels to so-called pseudo albedo, which is a subsurface irradiance reflectance not corrected for the directionality of the underwater light field (Q-factor) [5]. Channels at shorter wavelengths are used for water constituent retrieval.

We tested the atmospheric correction procedure with both aerosol types maritime and continental. It was found that maritime aerosols lead to higher pseudo albedo, and the shorter the wavelength, the bigger the difference (Fig. 3). Two identical datasets processed in either way were used in the water constituent retrieval module. Due to the low reflectance at short wavelengths, the dataset corrected for continental lead to very high chl-a and comparable low sm concentrations. As the results from the data corrected for maritime aerosols were much more realistic, aerosol type maritime was chosen for further processing.

The atmospheric correction procedure was run with MERIS channels 12 (778 nm), 13 (865 nm) and 14 (885 nm) as reference. The resulting pseudo albedos were found to have the same offset of about 0.2-0.4% reflectance in all channels (Fig. 4). The reason for this offset was not found, but could possibly lie in the sensor's calibration. Channel 14 was chosen for further

processing, since too low pseudo albedos in some datasets caused errors in the subsequent water constituent retrieval.

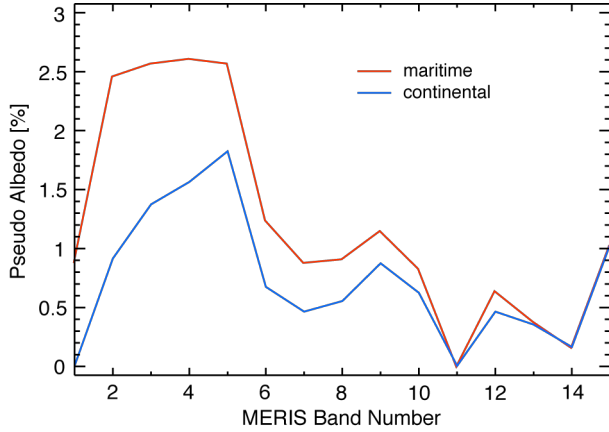


Figure 3. Subsurface pseudo albedos, atmospherically corrected for aerosol types maritime and continental, for sm concentration 1.5 g/m^3 , sm backscattering coefficient (from [10]) and reference channel 14.

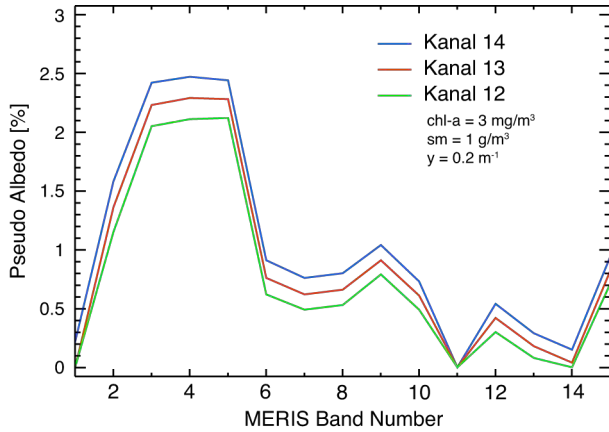


Figure 4. Subsurface pseudo albedos, atmospherically corrected with reference channels 12-14, for sm concentration 1 g/m^3 , sm backscattering coefficient 0.45 and aerosol type maritime.

Raising the estimated sm concentration causes an increase in backscattering, therefore the pseudo albedos after atmospheric correction increase with increasing sm concentration estimates (Fig. 5). Taking into account the findings of previous work on Lake Constance, an average of 1.5 g/m^3 was considered to be the best assumption for further analysis. Still, due to the high seasonal variation of sm concentrations ranging from 0.5 to 3 g/m^3 in pelagic zones, this assumption leads to considerable inaccuracies.

To analyse the influence of the backscattering model, the correction procedure was run with wavelength independent input scattering coefficients of 0.45 and $0.65 \text{ m}^2/\text{g}$. The pseudo albedo calculated with the

wavelength dependent coefficient by [10] used for further analysis was found to lie in between the results (Fig. 6).

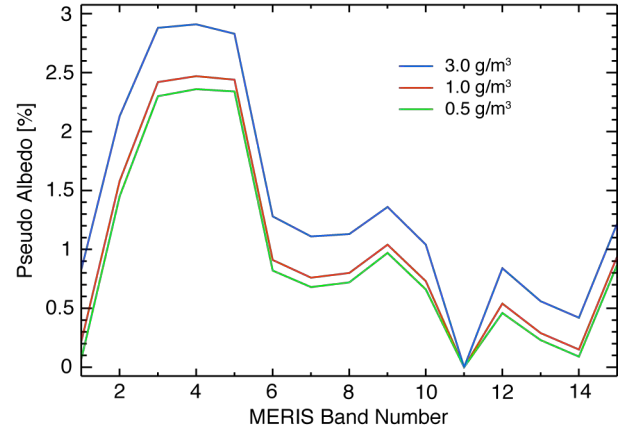


Figure 5. Subsurface pseudo albedos, atmospherically corrected with different sm concentrations, for sm backscattering coefficient 0.45, aerosol type maritime and reference channel 14.

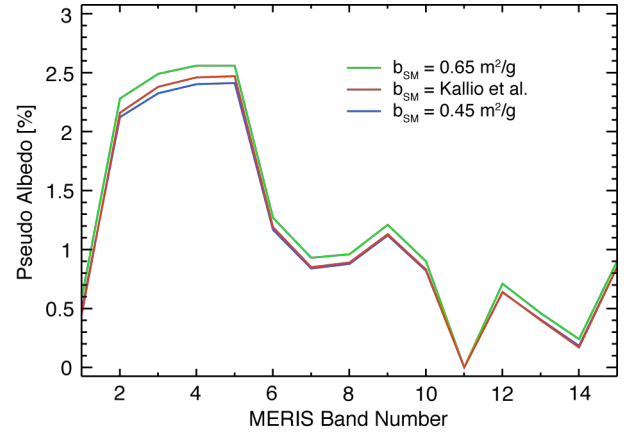


Figure 6. Subsurface pseudo albedos, atmospherically corrected with different sm scattering coefficients, for sm concentration 1.5 g/m^3 , aerosol type maritime and reference channel (14).

3.4. Water constituent retrieval

For the retrieval of water constituent concentrations chl-a, sm and y, the pseudo albedo in channel 1-8 (412-735 nm) is used. Initial values and maximum, minimum and tolerance thresholds for each parameters concentration are estimated according to the range of parameters occurring in Lake Constance [3]. Weighting factors can be set for each channel in use. By means of a Simplex algorithm, the simulated subsurface reflectance for varying constituent concentrations is then fitted with the subsurface reflectance from atmospherically corrected image pixels. The Q-factor correction is applied [6] iteratively during the optimization procedure, to meet the changing concentrations of water constituents at the specific sun-observer geometry.

The retrieval was originally processed with channels 1-8, all equally weighted. The fits between modelled and image derived subsurface reflectance spectra were found to differ by several tenths of percent even in channels 5-8 (Fig. 7).

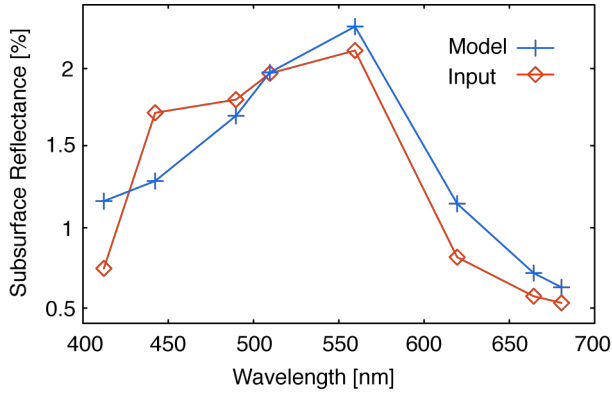


Figure 7. Fit of modelled and measured input subsurface reflectance, q -corrected with wavelength dependent sm scattering coefficient [10] and unweighted channels 1-8.

Since calibration, atmospheric correction and deviations from the sm scattering coefficient are assumed to cause largest errors in short wave channels, the weighting of channel 2 was reduced to 0.2 and channel 1 was entirely excluded from the retrieval. This improved the Q -factor correction and resulted in a more realistic subsurface reflectance, allowing for significantly better fits in channels 3-8. Additionally, although the algorithm was not forced to approximate the measured values in channels 1 and 2 anymore, the offsets in these channels increased only marginally (Fig. 8).

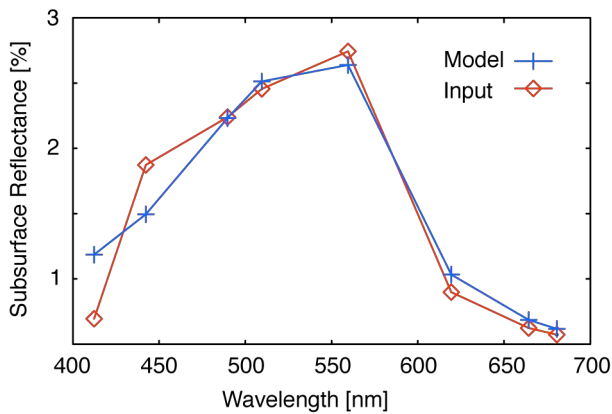


Figure 8. Fit of modelled and measured input subsurface reflectance, q -corrected with wavelength dependent sm scattering coefficient [10] and weighted channels 2-8.

For both channel weighting setups, we applied a scattering coefficient which decreases with increasing wavelength [10]. When using a scattering coefficient of

0.45 for all wavelengths, this again causes an inadequate Q -factor correction and leads to a subsurface reflectance that can't be reproduced by the model (Fig. 9). The same irradiance reflectance spectrum from 17 Apr. 2003 was used as input for all figures. Differences in input subsurface reflectance are solely due to Q -factor correction. The constituent concentrations for the best result (Fig. 8) are $chl-a=3.3 \text{ mg/m}^3$, $sm=0.65 \text{ g/m}^3$ and $y(400 \text{ nm})=0.15 \text{ m}^{-1}$.

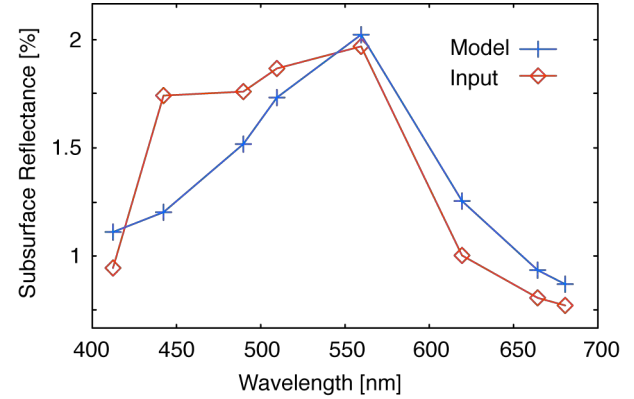


Figure 9. Fit of modelled and measured input subsurface reflectance, q -corrected with sm constant scattering coefficient 0.45 and weighted channels 2-8.

3.5. Empirical Recalibration Gain Factor

We adjusted the calibration for channels 1-3, 6 and 14 in order to retrieve realistic underwater reflectances by use of our atmospheric correction scheme. The originally calibrated level 1B input radiances were found to systematically miss the modelled subsurface reflectance after processing (Fig. 10).

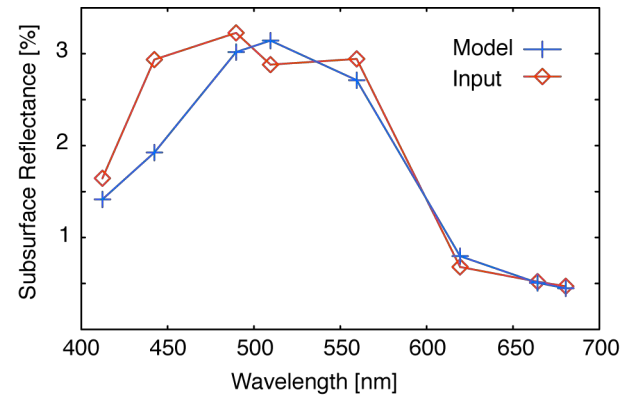


Figure 10. Fit of modelled and measured input subsurface reflectance spectra, with the same parameterization as in Fig.8, without recalibration.

Input radiances were therefore decreased by factor 0.98 for channels 1-3. Channel 6 was systematically recalibrated by factor 1.02 in order to retrieve reasonable spectra in the red region of the spectrum. Finally, we decreased the radiances of channel 14 by 2

percent (Fig. 8). Up to now, we could not investigate if these adjustments became necessary due to differences between modelled and real aerosol properties, or due to a slight error in the sensor calibration.

4. RESULTS

46 of the total 57 scenes represent at least sections of Lake Constance cloudless. Half of these scenes were processed error free with the setup presented in this work, leading to reasonable results such as for 17 Apr. 2003 (Fig. 8 and Fig. 11). This scene was recorded just at the begin of the spring bloom and reveals the diffusion of the bloom out of the shallow water areas (labelled white in Fig. 11). Nevertheless, further optimization of input parameters is required even for these datasets, in order to maximize the average model-input fit. Shallow water areas are not masked out in this procedure and must be expected as inaccurate.

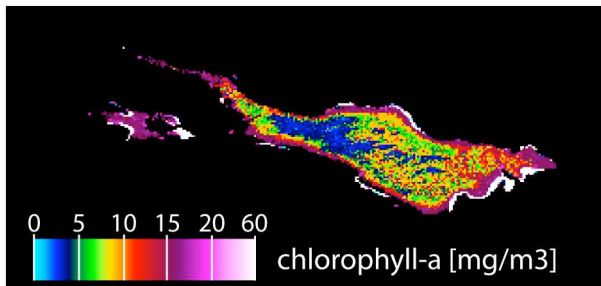


Figure 11. Chl-a concentrations on 17 Apr. 2003.

One of the main problems encountered in the processing of the remaining scenes was identified to be sunglitter, which at least partially occurs in about half the scenes acquired in summer season. Sunglitter leads to a reduction in temporal resolution of the time series, since it can not yet be corrected at the spatial resolution given by MERIS. Another problem was that in a quarter of the 46 scenes used for Lake Constance, the input at-sensor radiances have a significantly flat spectral slope with comparably high radiances in the NIR domain (Fig. 12). Since channel 14 (885 nm) is used for AOT estimation, high radiances at this bandwidth lead to erroneous AOT estimations, such as 0.65 m^{-1} for the 030926-spectrum depicted in Fig. 12. With such erroneous AOT values, the resulting subsurface reflectances after atmospheric and q-correction are zero for most and in particular for short wave channels, making impossible the subsequent water constituent retrieval. A solution to accurately account for this kind of input data anomaly is currently being looked for.

Normally, the AOT calculated by the atmospheric correction procedure has only small variation around the centre of Lake Constance.

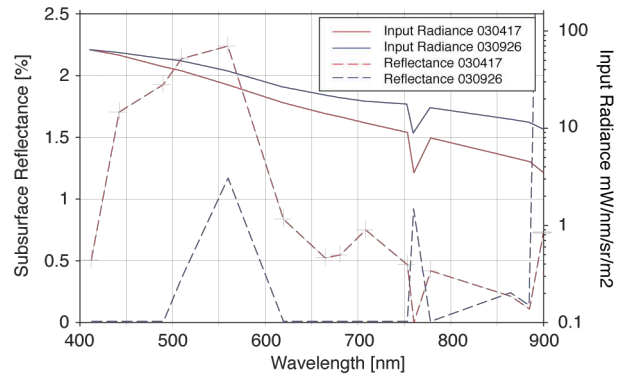


Figure 12. Input radiances before and subsurface reflectance after atmospheric and q-factor correction for 17 Apr. 2003 and 26 Sept. 2003.

Along the shore, strongly increasing AOT values are found (Fig. 13). This increase can be caused by adjacency effects, when path scattered radiance from neighbouring land surface is added to at-sensor radiances for water pixels. In some cases, such an unintended correction of adjacency effects through AOT can lead to fairly reasonable results, as it is apparently the case for the homogeneous southern shore in Fig. 14. For the northern shore, the increase in AOT overlaps an increase in sm concentration. In this case, the increase in AOT is caused by both, adjacency and the water optical properties. This effect needs to be considered in the interpretation of results for Lake Constance, and it will become even more relevant when processing smaller lakes in the future.

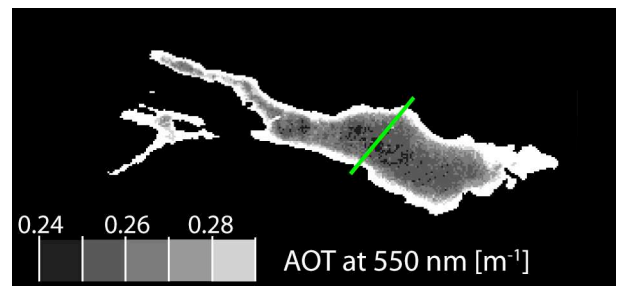


Figure 13. AOT at 550 nm on 17 Apr. 2003. The green line indicates the transect in Fig. 15.

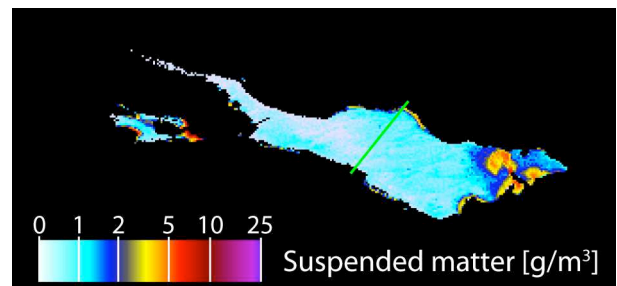


Figure 14. sm concentrations on 17 Apr. 2003. The green line indicates the transect in Fig. 15.

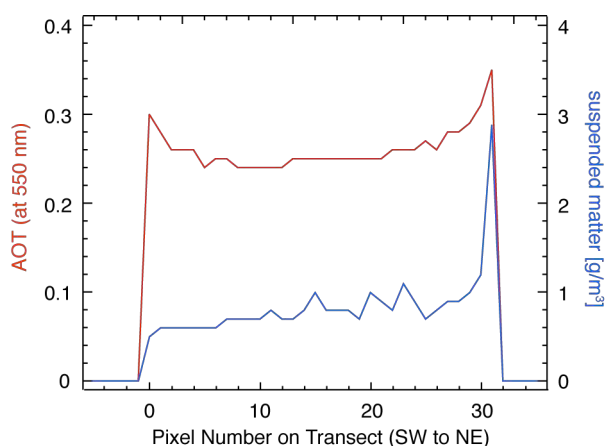


Figure 15. AOT values and suspended matter concentrations for the pixels on the transect depicted as green line in Fig. 13 and Fig. 14.

5. OUTLOOK

Regarding Lake Constance, an explanation for the flat input radiance slope in some datasets is needed, in order to conserve the approximately biweekly temporal coverage of the time series. With more datasets available for processing, we will finish the process of optimization described here, using in situ subsurface reflectance which is currently measured in field work for an update of scattering and absorption coefficients used by the model. Only then, we will compare the results with water quality monitoring data, aiming at the integration of satellite derived data into common monitoring programs. In a further step, an analogous optimization will be done with other Swiss lakes, exploring the limitations of MERIS due to its spatial resolution.

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